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Design and test of a device for acceleration reproducibility of hand held olive harvesters

Roberto Deboli[a,*], Angela Calvo[a,b], Christian Preti[a], Marco Inserillo[a]

[a]IMAMOTER Institute for Agricultural and Earth-moving Machines of C.N.R (Italian National Research Council), Strada delle Cacce 73, 10135 Turin, Italy;
[b]DISAFA (Department of Agricultural, Forest and Food Sciences and Technologies), Via Leonardo da Vinci 44, 10095 Grugliasco, Turin, Italy
***Corresponding author**: Roberto Deboli, IMAMOTER (Institute for Agricultural and Earth-moving Machines) of C.N.R. (Italian National Research Council), Strada delle Cacce 73, 10135 Turin, Italy; phone 0039 11 3977710; e-mail: r.deboli@imamoter.cnr.it

ABSTRACT

Hand held olive harvesters may cause severe HAV (Hand Arm Vibration) pathologies to the operators. The measured vibration data should be available to the end users in the instruction manual issued by the manufacturers, who should follow the procedures specified by a C type European standard.
Since the hand held olive harvesters do not have such a standard, manufacturers are not able to provide reliable data. This paper describes a test methodology in view of a C type European standard for these machines.
The work started with field activities to collect acceleration data to compare with laboratory results, as requested by the EN ISO 20643. A device to simulate the dynamic vibration response of olive tree branches was then designed, assembled and tested with different configurations, to obtain repeatable acceleration data of hand held olive harvester. When the final prototype was configured, a second laboratory was involved, equipped with a different measurement chain to test the reproducibility.

Keywords: hand held olive harvester, HAV, test reproducibility, vibration

1. Introduction

In many Mediterranean countries the olive groves are often on sloping terrain, where the self propelled harvesting machines are unable to work. Therefore the harvesting operations are performed manually, with low productivity and high costs, up to 50-70% of the cultivation revenue (Vieri and Sarri, 2008): these drawbacks are contrasted by the hand held harvesters (powered by an external pneumatic or electric source or by a small two-cycle engine). The fall of the olives is forced by the hand held harvesters by means of the mechanical impacts of special oscillating tools or the shaking of the branches (typical action generated by the hook type machines).
The detachment of the olives is not easy and several factors contribute to the difficulty of removing them. The olive is a small fruit with high attachment strength, generally borne on long hangers which hang downward, isolating the fruit from the applied vibration. A further difficulty is that many trees are old and have brittle scaffold branches weakened by disease or grafts (Fridley et al., 1972; Tsatsarelis, 1987).
The main three types of hand held olive harvesters are: beaters, combs and hooks (Fig. 1).

		
(a)	(b)	(c)

Fig. 1. Three types of hand held olive harvesters: beater (a), comb (b) and hook (c).

Beaters are machines with an oscillating head equipped with thin sticks in carbon fibre; harvesting is obtained by direct impact of sticks on olives or by vibration transmitted to the willowy branches. Normally the head is supported by 2 or more telescopic aluminium poles , up to 3.5 m in length. These machines are normally pneumatic or battery (12V) powered.
Electrical or pneumatic combs (flap type) have two combs with aluminium or plastic sticks moved back-and-forth, like a scissor. Normally the movement is carried out by a small piston fed by a pneumatic circuit at a pressure of 7-8 bar. Some models are battery powered (12 V). The heads can be mounted on extension poles of different lengths.
Hook type harvesters are driven by a little two-cycle engine or by an electric motor. They have a hook at the top of the pole. The engine produces an alternative motion of the pole and, therefore, of the hook. During the work the operator grabs the olive branch with the hook, which moves the branch with high frequency, detaching the fruits.
Being the hand held harvesters low weight machines, typically from 2 up to 15 kg, their working tools generate high vibration levels (in some models 30 m/s^2 as r.m.s. of Wh weighted acceleration are usual) which are transmitted to the operator hands.
The prolonged use of hand held vibrating power tools can result in the so called hand arm vibration syndrome (HAVS) of the muscle-skeletal, nervous and vascular peripheral structures of the upper limb (Bovenzi, 1998; Bovenzi, 2005).
Many researchers studied the olive harvesting made through self propelled machines that shake the log (Erdoğan et al., 2003; Torregrosa et al., 2009) or the main branches (Sessiz and Özcan, 2006) of the plants, whereas the olive harvesting made through hand held devices received less attention.
Torregrosa et al. (2006) published a paper on a hook type machine used to harvest apricots. In 2008 Torregrosa et al. studied the same machine when used to harvest peaches. Though the authors were primarily interested in the mass of fruits harvested, they report maximum acceleration peaks of 900 to 1000 m/s^2 and a maximum root mean square (r.m.s.) value of about 230 m/s^2 at 21 Hz (not frequency weighted).
Deboli and Calvo (2009) studied the grip forces applied by the operator to the handle of held olive harvesters using a capacitive sensor matrix.
Aiello et al. (2010) studied the level of operators' hand arm vibration exposure using three different hook type harvesters, reporting acceleration values of about 12 m/s^2.
Saraçoğlu et al. (2011) carried out tests on noise and vibration produced by some hook type olive harvesters and found that the vibration level transmitted to the hands produced finger blanching in 10% of the exposed operators after about seven months.
Çakmak et al. (2011) investigated the same issues in a flap type olive harvester and obtained similar results.
Manetto et al. (2012) studied the influence of materials used in flap-type harvester: the vibration generated by carbon fibre bars had r.m.s. values of about 12 m/s^2 vs about 21 m/s^2 generated by aluminium bars.

Nevertheless exposed workers have a wrong perception of the exposure effects to HAV, as underlined by Costa et al. (2013) and Vergara et al. (2008), which may pose health problems because of the lack of preventive actions.
Beside the scientific circles, the performance of the hand held olive harvesters is of great interest because, according to the 2006/42/EC Directive (2006), the manufacturers must declare the acceleration values in the machine instruction manual. The hand held olive harvesters are treated by a B type standard (EN ISO 20643: 2008) which establishes that the vibration measurements in laboratory must be within the range of measurements of the field tests, with low variability. As stated in EN ISO 12100: 2010, type B standards (generic safety standards) deal with one safety aspect or one type of safeguard that can be used across a wide range of machinery. Specifically, type B1 standards concern particular safety aspects (e.g. safety distances, surface temperature, noise), while type B2 standards treat of safeguards (e.g. two-hand controls, interlocking devices, pressure sensitive devices, guards). The vibration on hand held olive harvesters are therefore treated as B1 type standard.
The results from different laboratories must differ within specified limits (reproducibility condition), with well defined operating conditions close to the real process for which the machine was designed. Unfortunately, a C type standard to establish these operating conditions for these machines does not actually exist.
It should be therefore necessary to write a standard which could give the opportunity to the manufacturer to simulate the field operations using a device exploitable in laboratory and which guarantees repeatability and reproducibility characteristics (other than vibration magnitudes close to the field values).
To fill the gap, the Institute for Agricultural and Earth-moving Machines of C.N.R. (Italian National Research Council) of Turin (from now on called IMAMOTER) designed and assembled a device to replace the olive tree for the vibration acquisition of hand held olive harvesters in laboratory.
A first device was equipped with olive branches taken from an olive tree, but the acceleration values were highly influenced by the elastic variation of the branches, which lost water and leaves day after day. Different frames with wires of several materials were then tested, to simulate the damping effect produced by the leaves, but only a wooden framed device with multifilament polypropylene UV stabilized wires gave good results in terms both of repeatability and reproducibility. This final device was then tested in another laboratory in Turin, obtaining data comparable with the field vibration values, as requested by the EN ISO 20643.

2. Materials and methods

The wooden framed device with multifilament polypropylene UV stabilized wires was firstly built at the IMAMOTER. Afterward, two olive harvesters, beaters type, were used in field during the harvesting season in autumn 2012: the laboratory vibration acquisition started after the measurement campaign in field.
The mean acceleration values obtained in field were the target to be reached in two laboratories (described in the 2.2 section) using the device designed, assembled and presented in this work.

2.1 The olive harvesters

Table 1 reports the characteristics of the two olive harvesters, beater type, used both in field and laboratory. They are battery powered (12 V) units, named J1 and J2, manufactured by the same company with an oscillating head equipped with eight carbon fibre sticks.
These beaters were supplied by the manufacturer, from the very beginning interested to know their hand arm vibration values in different operative conditions (idling and full load), both in laboratory and in field.
The J2 model features an electronic control to decrease the number of beats per minute (bpm), and consequently the electric consumption, when the operator moves from one tree to another (idling state).

Table 1 Technical characteristics of the hand held olive harvesters.

Technical data	model J1	model J2
Working capacity (kg/h)	80-120	100-400
Beats per minute (bpm)	1150	400-1400
Head mass (g)	750	750
Telescopic pole mass (g)	900	900
Telescopic pole length (mm)	1700-3100	1700-3100
Sticks length (mm)	350	350
Stick diameter (mm)	5	5
Supply voltage (V)	12	12
Current consumption (Ah)	3-5	2-5
Standby consumption (Ah)	-	0.5
Tangential stick speed (m/s)	3.67	4.14

All tests, in field and in laboratory, were carried out with a pole length of 1830 mm and the overall length of both machines was 2050 mm.

2.2 Field and laboratories sites

Field tests were performed during the harvesting campaign in a private olive tree grove of *Olea Europea*, variety Leccino, located in Stella (Savona, Italy); the coordinates are 44°23' 48" N and 8°29' 36" E.

Laboratory tests were carried out at the IMAMOTER and at the DISAFA Department, Mechanical Section (University of Turin) in Grugliasco (Turin), with different measurement chains and operators.

2.3 HAV measurements

2.3.1 Measurement procedures

Tests were always performed in idling and full load conditions both in field and laboratory.

Accelerations along the three perpendicular axes (a_x, a_y, a_z) were measured simultaneously following the recommendations of the EN ISO 20643/A1: 2012 standard. These measurements were carried out both at the front and at the rear handle of the harvesters and frequency weighted using the weighting curve *Wh* as described in the ISO 5349-1: 2001 standard. The acquisition time during each test was two minutes, to reach a stabilized signal.

The evaluation of vibration was based on the vibration total value (a_{hv}), defined as the square root of the sum of the squares (r.m.s.) of the frequency-weighted accelerations a_{hwx}, a_{hwy} and a_{hwz} along the individual axes (Eq. 1):

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (1)$$

Each test was repeated five times for each operator and for each hand held olive harvester. The Coefficient of Variation (CV) of each five vibration total values a_{hv} recorded was calculated and compared with the upper limit value 0.15 to validate the measurement. When the CV value was greater than 0.15, then the testing continued until five consecutive measurements gave an acceptable value of CV.

The measurement result a_h (m/s²) was then determined as the arithmetic mean of vibration total values over all runs and operators. The a_h value was calculated both at the front and at the rear handle.

To determine and verify the vibration emission values, the EN 12096: 1997 requires the calculation of the uncertainty K with a specified procedure..

The laboratory acceleration a_h (from now on denoted a, as reported in EN 12096) was therefore rectified with the uncertainty K to get the final combination a+K. K (Eq. 2) was derived from the standard deviation of reproducibility σ_R of two laboratories (Eq. 3):

$$K = 1.65 \cdot \sigma_R \quad (2)$$

$$\sigma_R = \sqrt{\sum_{i=1}^{2} (a_i - \bar{a})^2} \quad (3)$$

where a_i are the vibration emissions achieved at IMAMOTER and DISAFA and $\bar{a}$ is the mean value of a_i .

The EN ISO 20643 requires also that the arithmetic mean value of the measurements in laboratory (a) must reflect the upper quartile of the measurements in field. To check this requirement, the ratio between $a+K$ and the upper quartile was calculated: a ratio of 1 is the target, results greater or lower than 1 reveal that laboratory and field measurements differ more or less significantly.

Operators have a great influence on the uncertainty of measurements (ISO GUM, 2003), especially when the feeding force increases the coupling between the hand and the tool (Moschioni et al., 2011). In this work, however, since the feeding force exerted by the operator on the tool is very limited, it was not measured.

2.3.2 Measurement chain in field and at the IMAMOTER laboratory

Two tri-axial accelerometers ICP (Integrate Current Preamplifier) by PCB (SEN020 model, 1 mV/g sensitivity, 10 g mass) were oriented according to the EN ISO 20643 standard and secured to the harvester handles (front and rear) by means of metal supports wrapped with metallic screw clamps, as suggested by Ainsa et al. (2011) to reduce the uncertainty of hand-arm vibration measurements. Signal wires from accelerometers were fixed to the rod by adhesive tape.

The output signals from the accelerometers were processed in real time through a NI (National Instruments) 9402 (six channels), while the software Sound and Vibration Assistant (National Instruments) was used to post-process the data. A plastic ribbon assured the electrical insulation between the accelerometers and the metallic rod of the harvester. The measurement chain, both in field and at the IMAMOTER laboratory, was previously calibrated.

2.3.3 Measurement chain at DISAFA

Two Larson Davis Human Vibration Meter type HVM100 were connected to a tri-axial accelerometer ICP by PCB, type SEN020, 1 mV/g sensitivity (front handle) and an accelerometer PCB 356A02, 10 mV/g sensitivity (rear handle). The accelerometers were secured to the handles by means of rigid adapters fixed to the pole by metallic screw clamps. Also in this case the measurement chain was previously calibrated.

2.3.4 Operators

Six operators were involved in both field and laboratory tests. Their anthropometric data are collected in Table 2. According to the EN ISO 20643, three operators were involved in each laboratory during the final set of tests.

Table 2 Operators data.

Operator code	Height (cm)	Mass (kg)	Worksite
1	173	80	IMAMOTER laboratory
2	170	65	DISAFA laboratory
3	180	95	In field and DISAFA laboratory
4	177	70	DISAFA laboratory
5	185	90	IMAMOTER laboratory
6	170	65	IMAMOTER laboratory

The accelerometer position at the left hand was identified for each operator according to his anthropometric characteristics (Fig. 2). The position of the rear accelerometer was fixed in correspondence of the power switch.

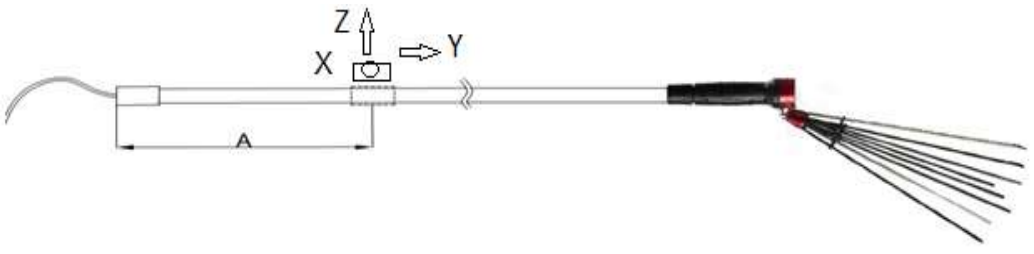

Fig. 2. Accelerometer positions and directions of vibration measurement on the harvester pole. "A" represents the distance between the two tri-axial accelerometers positions.

2.4 Device design and construction

The goal was to design a simple and cheap tool to simulate the behaviour of the olive branches within satisfactory reproducibility limits.

A wooden prototype was designed, light (15 kg mass, inclusive of the nine iron masses) and easy to transport and to assemble (Fig. 3).

Fig.3. The prototype alone (left) and with the J2 model harvester at work (right).

A 2000 mm high and 500 mm wide wooden chassis built with pinewood (joist dimensions 50 × 30 mm) supported a wooden frame (600 mm wide and 500 mm high) with both vertical and horizontal wires. The upper end of the vertical wires (spaced 50 mm apart) were secured to the frame, whereas the lower end was free and loaded by a 1 kg iron mass. The use of 1 kg masses was decided after many measurements carried out in field in autumn, during the olive harvesting campaign. The forces to be applied to laterally bend of 2 - 3 cm the smaller twigs (diameter from 2 until 5 mm) were measured using a dynamometer Imada, DPS model (Imada Inc.3100 Dundee Rd, Northbrook, IL 60062, USA) fitted with a load cell with a capacity of 0-200 N and ± 0.2% full scale resolution. These measurements showed that an average force of 10 N was required.

Masses of 1 kg were added to the lower end of each vertical wire of the device, to reproduce such 10 N force. These masses induce the strength that the sticks meet when rotate, exactly like the tree smaller twigs do. During the rotation the horizontal component of the force generated by the stick on the wire is 10 N.
On the right of figure 3 it is possible to see the lateral displacement of the wires produced by the rotation of the sticks.
The horizontal wires (spaced 40 mm apart and secured at both end to the frame with a pre-tension load of 10 N) interweaved the vertical wires.
Different wire materials were initially tested (Fig. 4): nylon rope, natural fibre (soon rejected for its quick wear) and plastic covered wires (3 mm diameter). The last ones gave good results in term of dynamic response, but the plastic cover rapidly wearied out. Multifilament polypropylene UV stabilized wires, braid 16 spindles, 4 g/m specific mass, 90 kg breaking load were then used: they were softer and more pliable, but provided a good mechanical resistance.

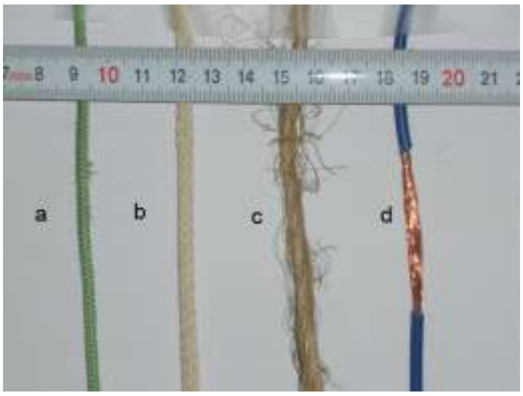

Fig. 4. Tested wires. a: multifilament of stabilized polypropylene UV; b: nylon rope; c: natural fibre (jute); d: plastic covered wires.

Concerning the wires wearing, specific tests were not performed (as requested, for example, by EN 892: 2012) but it was observed that some wires (especially the horizontal ones) had to be replaced after 40’ of real work (it means after around 20 tests). The partial wires wearing did not affect the acceleration values.
To emulate the variable tree height and consequently the different paths to reach the fruits, tests were performed with the centre of the frame at 1850 mm and 3020 mm from the floor (low and high position) because the variable height may have an effect on the effort exerted by the operator’s hands in gripping the machine handles.
This prototype in its final version was tested at the IMAMOTER laboratory with operators 1, 5, 6 and at the DISAFA laboratory with operators 2, 3 and 4.

2.5 Tests in laboratory

Three group of tests were conducted in laboratory to find the optimal device configuration to be used with the specific harvester. The first set concerned the comparison among the two hand held olive harvesters and involved two operators at the IMAMOTER laboratory. The second referred to the device position (low and high) using the J2 harvester with two operators at IMAMOTER (1 and 6) and one operator (the number 4) at the DISAFA laboratory. The last group of tests involved all operators of the two laboratories with the J2 harvester and the device in low position.

2.6 Operators' behaviour in field and in laboratory

In field the angle between the vertical projection of the canopy to the ground and the olive harvester was deduced by the movies, while the angle between the olive harvester and the frame was measured in laboratory.
In laboratory, each operator had to reach, in a sequential manner, the four hypothetical quadrants in which the frame with wires could be split (this fact forced the operator to tighten the front hand to direct the head with sticks to the target).
At the first insertion of the sticks of the J2 harvester among the wires, the number of beats incremented from 400 bpm until 1400 bpm.
The operator had to keep the sticks inside the wires for a period of 10 seconds. Then he had to move the harvester head in another quadrant (following a clockwise rotation), where the sticks remained for the same period of time. The test had to be completed within a period of two minutes. A red ribbon (positioned at 8 cm from the tip of the sticks) was glued on sticks to show to the operator the right portion to be inserted into the wires.

2.7 Data processing

2.7.1 Check of the DC shift

The possible presence of a DC-shift in acceleration data, due to the impacts between the harvester sticks and the natural or artificial obstacles, was ascertained (Maeda and Dong, 2004; Paddan, 2004). Since the *x* axis is the most solicited, as proposed by Peretti et al. (1993) the DC shift presence was checked by securing two accelerometers to an aluminium block placed near the left hand grip and connecting one of them to a Bruel&Kjaer mechanical filter (UA0553); the 1/3 octave analysis did not reveal any low frequency energy.

2.7.2 Data analysis

The acceleration data were organized into spreadsheets and then processed using the IBM SPSS Statistics 20 software package. Front and rear handle values were always treated separately to avoid any ambiguity.
In all the cases, the normal distribution of the data and the variance homogeneity was detected, to let the use of the ANalysis Of VAriance (ANOVA) procedure. The one-way ANOVA test was applied in the harvesters and in the laboratories comparisons (significance level p=0.05).
When the previous conditions were non verified, a non parametric test was applied: the U test of Mann - Whitney was used for two independent samples (in the case of the comparison between the low and high device position): also in this case it was assumed a significance level equal to 0.05.

3. Results and discussion

3.1 In field

During the field tests it was observed that the variety of the olive tree had little effect on the measured accelerations, while the layout of the thin branches significantly influenced the dynamic response of the harvesting tools.
In field the average angle between the olive harvester and the vertical projection of the canopy to the ground varied from 30° to 80°, depending on the tree height.
The behaviour of the two harvesters, J1 and J2, was quite different. In the idling condition the model J1 vibrated more, but at full load the acceleration of model J2 was definitely higher than model J1 (almost 10 m/s^2 higher in the front handle, as shown in Table 3). The better performance of model J2 in idling came from the reduced number of beats per minute forced by its electronic control.
Table 3 Descriptive data (mean, Standard Deviation (SD) in brackets and range) of the vibration measurements in field.

	Idling (m/s^2)	Full load (m/s^2)

	Mean (SD)	Range	Mean (SD)	Range
J1-Front	11.4 (0.6)	10.9-11.8	19.9 (1.2)	17.7-21.0
J1-Rear	9.6 (0.0)	9.6-9.6	16.5 (1.2)	14.3-17.9
J2-Front	4.4 (0.7)	3.7-5.1	29.8 (3.1)	26.0-36.2
J2-Rear	3.2 (0.0)	3.1-3.2	24.3 (2.5)	21.9-29.6

The box whisker graph of the field measurements in figure 5 shows the data dispersion.

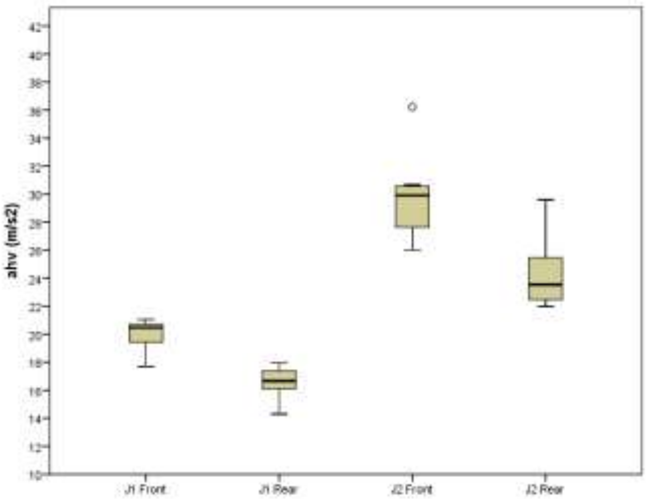

Fig. 5. Box whisker graph of vibration values measured in field for each handle in the examined harvesters (J1 and J2).

No statistical analysis was applied to these tests, because the harvester was the discriminating factor; moreover, the same operator was involved in all tests.
Cerruto et al. (2010) studied the vibration transmitted to the operator by electric hand held olive harvesters (battery powered) similar at J1 and J2 but of a different manufacturer, reporting acceleration average values of about 20 m/s^2 for both the handles at full load: in this paper averages of 18.2 and 27.0 m/s^2 were obtained.
These Authors suggested more laboratory tests to characterise materials and machines, to ensure standard and controlled conditions, maintaining the external factors (operator's influence, operating modes, load parameters) as constants as possible.

3.2 Laboratory tests

Different tests were performed, to choose the device configuration to match the repeatability and reproducibility requests.
In laboratory the angle between the olive harvester and the frame was nearly constant (65° - 70°) for all the operators (because they had quite the same height) with the device at the low position, whereas it changed to 45° with the device at the high position.

3.2.1 Comparison between the harvesters

The investigation concerned the idling state and the full load with both models J1 and J2. The tests were conducted with the operators 1 and 6 at the IMAMOTER laboratory.
Table 4 shows the front and the rear arithmetic mean values (a) of the tests and corresponding Standard Deviations (SD) in idling and full load conditions. In this last case the J2 emissions (a:

26.9 m/s^2 front, 24.4 m/s^2 rear) were always higher than model J1 (*a*: 20.6 m/s^2 front, 18.9 m/s^2 rear) with corresponding higher standard deviations. On the contrary, the J2 model reported lower acceleration values at both handles in the idling condition (4.2 m/s^2 front, 2.8 m/s^2 rear) than J1 (13.9 m/s^2 front, 9.9 m/s^2 rear), as observed in field.

Table 4 J1 and J2 front and rear measured emission values (*a*) and corresponding Standard Deviations (SD) at idling and full load conditions.

	Idling (m/s^2)				Full load (m/s^2)			
	Front		Rear		Front		Rear	
	a	SD	*a*	SD	*a*	SD	*a*	SD
J1	13.9	0.5	9.9	1.8	20.6	1.4	18.9	1.9
J2	4.2	0.3	2.8	0.4	26.9	3.1	24.4	3.1

The ANOVA procedure confirmed the statistical difference between the two harvesters, in both states and at both handles (with asymptotic significance always at 0.000).

J2 gave higher acceleration values at full load and was more difficult to handle by the operators (as explained by higher standard deviations): from this moment on, only the J2 harvester was used, because the device must be able to work with high solicitations, that seems to be very useful for the olives detachment (as reported by users).

3.2.2 Device position

Tests on high and low device position exhibited differences between the operators 1 and 6 of the IMAMOTER laboratory, as well as for the operator 4 at DISAFA (Table 5).

Table 5 Front and rear arithmetic mean values (*a*) registered at IMAMOTER and at DISAFA with the device in low and high position, with corresponding Standard Deviations (SD).

	IMAMOTER Front (m/s^2)		IMAMOTER Rear (m/s^2)		DISAFA Front (m/s^2)		DISAFA Rear (m/s^2)	
Device position	*a*	SD	*a*	SD	*a*	SD	*a*	SD
Low	29.1	3.1	26.5	4.4	26.1	3.2	26.0	3.2
High	32.9	3.7	29.7	4.8	31.6	2.4	29.4	2.1

In the high position the vibration values was always higher, at both the handles: in addition, the U test of Mann- Whitney proved that for the operator 1 the high or low position of the device made no difference, whereas for operators 4 and 6 differences were observed on the front handle.

During these tests it was also observed that in the higher device position the operators 4 and 6 were inclined to lay the sticks over the wires, instead to move them inside the grid. For this reason, it was decided to execute the next tests with the device positioned only on the floor (low position).

3.2.3 Results between the two laboratories with the device in low position

The J2 harvester used with the wooden device in the low position gave good results in the two laboratories.

Front and rear emissions and Standard Deviations (SD) measured are shown in Table 6. The ANOVA procedure did not point out differences between the two laboratories, with an asymptotic significance of 0.72 for the front handle and 0.86 for the rear.

Table 6 Measured vibration levels and Standard Deviations (SD) obtained at the IMAMOTER and DISAFA labs with the device in low position.

	Measured emissions *a* (m/s^2)		SD (m/s^2)	
	Front	Rear	Front	Rear
IMAMOTER	29.5	27.3	3.3	4.4
DISAFA	30.1	27.6	5.2	3.5

When comparing the measurement points, it always emerged (in field as in laboratory) that the acceleration values were higher in the front handle (left hand) and lower in the rear handle (right hand) both in idling and full load condition, for each operator.

3.2.4 Field and laboratory comparison

In the previous paragraphs, the acceleration values were calculated only to determine the optimal device configuration. According to the EN ISO 20643, they were combined with the uncertainty variable K and compared with the upper field quartile obtained in field (Table 7).

Table 7 Front and rear measured emissions in the two laboratories, upper quartile measured in field and their ratio.

Laboratory/handle	Measured emissions (m/s^2)			Upper quartile field (m/s^2)	Ratio
	a	K	a+K		
IMAMOTER/front	29.5	0.7	30.2	30.5	0.99
IMAMOTER/rear	27.3	0.3	27.6	25.2	1.09
DISAFA/front	30.1	0.7	30.8	30.5	1.01
DISAFA/rear	27.6	0.3	27.9	25.2	1.11

The ratio ranges from 0.99 to 1.11; only in one case (IMAMOTER front) the vibration value from the laboratory is lower than its counterpart from the field, but also in the other conditions the ratio is nearly fitting 1 (which establishes the likeness of the laboratory tests with the field observations).
Compared with the results reported in other works with hedge trimmers (Heaton and Hewitt, 2011), they are more than acceptable.
Heaton and Hewitt in their work remark that the fatigue and the operator's behavior affect the hedge trimmers acceleration values registered during the tests, causing an high dispersion of the acquired data.
In this work the hand held olive harvesters have a lower mass (under 2 kg) than the hedge trimmers, but the high acceleration values generated are able to produce a deep tiredness of the operator. It is therefore necessary that more operators rotate during the tests.

3.3 Axis solicitation

The more stressed axis was always the X (Fig.2) and this is due to the mechanical movement of head sticks. This situation is verified both in field and in laboratories (Table 8), to confirm that the position of the wires in the device imposes to the sticks of the harvester head the same behavior of the olive branches.

Table 8 Frequency weighted acceleration along the individual axis recorded in three tests: in field (operator 3), at IMAMOTER (operator 1) and DISAFA (operator 4) laboratories.

		Front acceleration axis (m/s^2)			Rear acceleration axis (m/s^2)		
Place	Operator	a_{hwx}	a_{hwy}	a_{hwz}	a_{hwx}	a_{hwy}	a_{hwz}

Field	3	23.6	2.4	11.7	20.7	2.7	6.9
IMAMOTER	1	29.2	1.4	9.3	24.9	2.1	4.6
DISAFA	4	29.8	1.3	8.1	27.4	1.9	3.5

3.4 Spectral analysis of vibration acquired in field and in laboratory

In figure 6 are represented the acceleration mean values measured along the 3 axes in field and in laboratory in function of the frequency. The black dashed line represents the acceleration mean values of operator 3 in field. Continuous colored lines represent the acceleration mean values of operators 1,2,4,5 and 6 in laboratory.

The graphs illustrate the acceleration values measured both at the front and at the rear handle. It is possible to see how trends are similar in frequency both in field and in laboratory: only the magnitude of the acceleration (which depends on the operators' behaviour) is different. Moreover the values obtained in laboratory are very similar to each other, regardless of the operator.

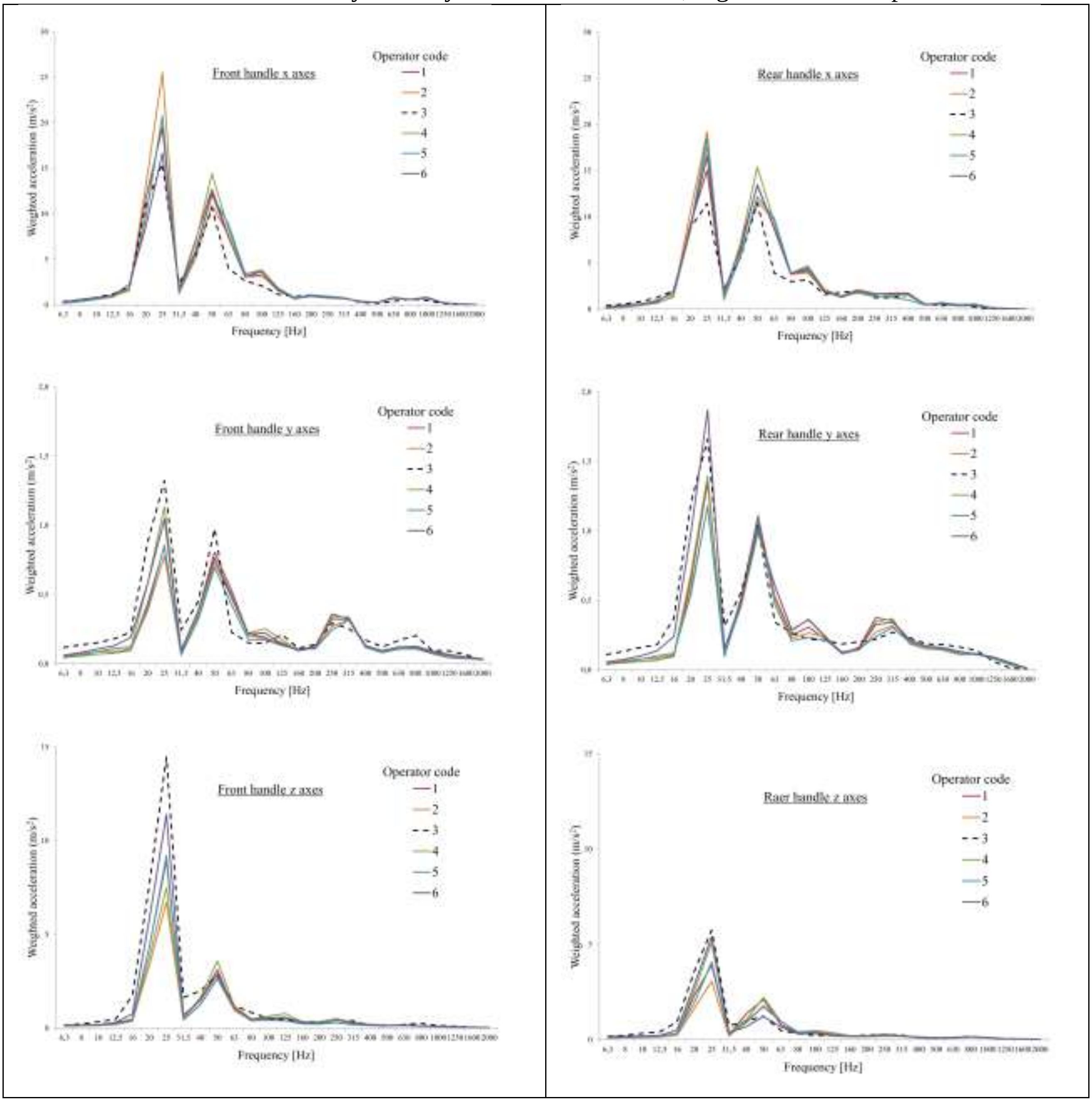

Fig. 6. Acceleration mean values measured along the three axes in field and in laboratory, front handle (left) and rear handle (right).

4. Conclusions

This paper presents the results obtained in laboratory with an easily assembled device to define a test procedure to draft a C type standard for the vibration measurement of the hand held olive harvesters.

The starting point was the analysis of EN ISO 20643 which states that the vibration magnitudes in laboratory tests must be within the range of measurements made in the field. Laboratory tests require also reproducible conditions and it is therefore essential that different laboratories obtain the same results within specified limits.

To this purpose in some cases an artificial process may be used which is not in line with the typical use of the machine in the field but which provides equivalent data.

For this reason a simple device was designed and assembled to emulate, in laboratory, the obstacle produced by the tree branches during the olive harvesting. This task was reached using a wooden frame equipped with multifilament of polypropylene wires preloaded in a suitable way.

The laboratory tests started with two different models of hand held olive harvester, J1 and J2; subsequently, only the J2 harvester was used.

To emulate the gestures of the operator working in the field the device was tested in high and low position. The acceleration values in these two configurations were unstable and with the frame in high position some operators manifested fatigue early than in the low position (because the left hand was constantly over the shoulder). For these reasons tests followed with the frame only in the lower position, with good results in the two laboratories.

The mean values of vibration (a) were then added to the measurement uncertainty K and compared to the upper quartile of the mean vibration data obtained in field: the ratio was very good (quite close to the optimum value 1), also compared with the results reported in other works (where different type of hand held machines were tested).

The tests carried out on the device and the good results provided by it in two laboratories for the acceleration values in terms of repeatability and reproducibility are encouraging for the drafting of a C type standard for these machines.

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